Environmental health :
risks posed by PCBs

Background Paper

BP-392E

ENVIRONMENTAL HEALTH: RISKS POSED BY PCBs

William Murray
Science and Technology Division

November 1994

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Canada Communication Group -- Publishing
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Catalogue No. YM32-2/392E
ISBN 0-660-15888-4

CE DOCUMENT EST AUSSI
PUBLIÉ EN FRANÇAIS

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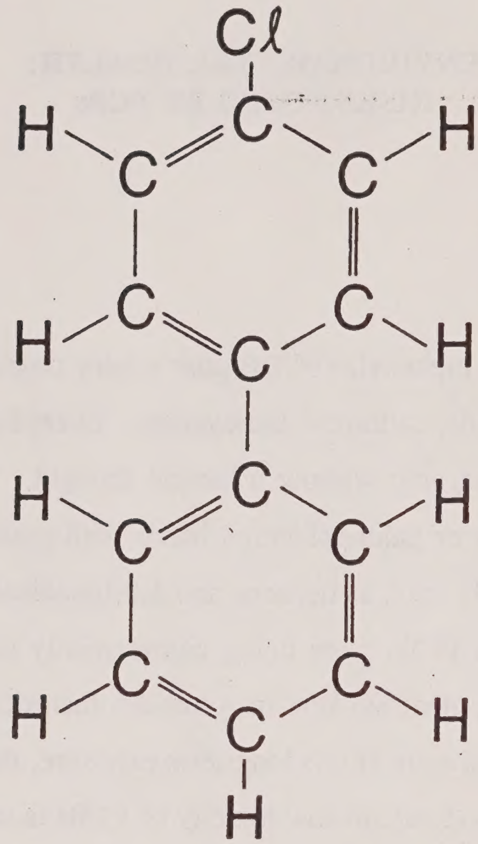
INTRODUCTION

Polychlorinated biphenyls (PCBs) pose a very much lower health risk than such toxic chemicals as vinyl chloride, cadmium and cyanide. Everyday, people use chemicals that are far more toxic and carcinogenic without a second thought. For example, it is common practice to clean paint brushes or paint-splattered hands with gasoline, yet gasoline contains a number of chemical compounds, such as benzene and 1,3-butadiene, that are substantially more dangerous than PCBs. While PCBs were being commercially manufactured, from the early 1930s to 1980, electrical-equipment workers in American factories were exposed every day to high concentrations of them. In spite of this long-term exposure, these workers experienced few adverse health effects. The moderate-to-low toxicity of PCBs is in sharp contrast to the public perception of them as extremely toxic and cancer-causing. This high level of public anxiety has severely hampered the Canadian government's effort to manage waste PCBs effectively.

PCBs: THEIR CHEMICAL STRUCTURE AND INDUSTRIAL USE

PCBs are a group of synthetic chemicals belonging to the family of organic chemicals known as chlorinated hydrocarbons. They consist of a biphenyl molecule, made up of hydrogen and carbon, to which chlorine atoms can be attached. Figure 1 shows the typical molecular structure of a PCB. Chlorine atoms (Cl) can chemically bond on to any of the other nine hydrogen (H) sites, giving a total of 209 possible chlorine arrangements or isomers.

Figure 1
Typical Structure of a PCB



PCBs are extremely stable, relatively fire-resistant, and non-corrosive. These characteristics made them very useful in a wide range of applications, such as hydraulic fluids, dye solvents and plasticizers.(1) The major application of PCBs, however, has been in electrical equipment. In the 1930s, the electrical industry began using PCBs in transformers, the ballast of fluorescent lights, electromagnets and in other electrical equipment where a stable, fire-resistant, non-conducting oil was required.(2)

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(1) M.J. Charles and R.A. Hites, "Sources and Fates of Aquatic Pollutants," *Advances in Chemistry*, Vol. 216, 1987, p. 365-389.

(2) Canadian Council of Resource and Environment Ministers, *The PCB Story*, August 1986, p.2.

PCBs: HOW THEY BECAME FEARED

Until approximately 1968, PCBs were considered to be one of the wonder products of the chemical industry. The possibility that PCBs might pose a human health risk became a concern only after two separate incidents, one in Japan and one in Taiwan, where cooking oil became contaminated by PCBs. The more serious occurrence was the Japanese Yusho incident, where nearly 1,500 people consumed contaminated oil, ingesting 0.5 to 2 grams of PCBs per person. Some individuals became severely ill with such symptoms as eye discharge, systemic gastrointestinal symptoms with jaundice, edema, abdominal pain and chloracne (a very persistent form of skin eruption that can last for up to three years).

All the Yusho victims recovered; however, there were long-term consequences. Pregnant Yusho victims had shortened gestational periods and gave birth to smaller-than-normal babies who as children exhibited slight reductions in mental development and impaired motor skills. A four-year follow-up study indicated that the development of these children continued to lag behind that of their peers.

A large research effort focusing on PCB toxicology and carcinogenicity was prompted by this outbreak of illness. Surprisingly, animal testing failed to demonstrate PCBs to be a highly toxic class of chemicals. These results were corroborated by health surveys of electric industry employees. Workers who had spent 30 years in daily physical contact with PCBs showed few if any of the health problems exhibited by Yusho victims.

PCBs are susceptible to thermal conversion to polychlorinated dibenzofurans (furans) and polychlorinated dibenzodioxins (dioxins).[(3)] Chemical analysis of the contaminated cooking oil revealed that it contained, in addition to PCBs, relatively high concentrations of furans and quaterphenyls and a low concentration of dioxins. It is now hypothesized that the action of high-temperature frying converted some of the PCBs to furans and dioxins which, it is believed, caused the Yusho illnesses.[(4)] It should also be noted that, even without heating,

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(3) In this conversion, the phenyl rings of the original PCB are cleaved apart, but still bonded through one oxygen bridge to form a furan, or through two oxygen bridges to form a dioxin.

(4) Environment Canada, *Polychlorinated Biphenyls (PCBs) - Fate and Effects in the Canadian Environment*, Beauregard Press Limited, EPS 4/HA/2, May 1988, 90 p.

dioxins and furans occur as low-level contaminants of PCB oils (less than 2 ppm) as a result of the normal synthetic process.[5] Although pure PCBs have been vindicated in the scientific literature, the belief that PCBs are deadly remains firmly fixed in the public's mind.

HEALTH EFFECTS

A. Toxicology

There are no documented cases of human death due to acute PCB exposure. Victims of industrial PCB accidents report chloracne, eye discharge, swelling of the upper eyelids, hyperpigmentation of the nails and skin, numbness of limbs, weakness, muscle spasms and chronic bronchitis. These symptoms, which are similar to those associated with poisoning by a variety of chlorinated organic compounds, are believed due to the dioxins and furans that normally contaminate PCBs.[6] According to Dr. M.A. Ottoboni, a toxicologist with the California Department of Health Services:

> There is a wealth of data in the scientific literature on the toxic effect of PCBs. Acutely, PCBs are of a sufficiently low order of toxicity by all three routes of exposure [dermal, inhalation, oral] to be classed as legally nontoxic.[7]

B. Teratology

There is some indication that prenatal exposure to PCBs may affect birth size and, to a lesser extent, gestational period. A comparative study was conducted of 242 newborn infants whose mothers consumed fish from Lake Michigan and 71 infants whose mothers did not eat such fish. PCB exposure was indirectly determined by contamination levels in fish and directly from serum levels in the umbilical cord. Exposed infants were 160 to 190 grams lighter than the control group and their heads were 0.6 to 0.7 centimetres smaller. Head circumference

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(5) M.A. Ottoboni, *The Dose Makes the Poison: A Plain-Language Guide to Toxicology*, Bacchus Press, Berkeley, 1984, p. 163-167.

(6) *Ibid*.

(7) *Ibid*.

was disproportionately small in relation to both birth weight and gestational age. The gestation period for women who consumed Lake Michigan fish was 40.31 weeks, as compared to 40.82 weeks for the control group. Control analyses showed that none of these effects was attributable to 37 potential confounding variables, including socio-economic status, maternal age, smoking during pregnancy, and exposure to polybrominated biphenyls.[8] It should be emphasized, however, that this study does not prove that PCBs were the causative agents. Fish in the Great Lakes are contaminated with dioxins, furans and a wide variety of industrial and agricultural chemicals, any one or combination of which might have caused the observed reduction in infant development.

C. Carcinogenicity

PCBs are routinely described as "cancer-causing" or sometimes more conservatively as "linked to cancer." This link is based upon the United States Environmental Protection Agency (EPA) decision to classify PCBs as potential carcinogens,[9] but it is tenuous.

One means by which a chemical can lead to cancer is by causing a mutation in a cell's genetic material. PCBs have been investigated for mutagenic activity against several standard test strains of bacteria, the fruit fly *Drosophila melanogaster*, human lymphocyte cells, and *in vivo* with rats. All test results were negative.[10]

Whether or not a chemical is carcinogenic can often be determined by conducting statistical studies of human populations subjected to long-term exposure. An epidemiology study of approximately 2,600 electrical industry workers in the United States indicated a slightly higher than normal incidence of death from rectal and liver cancers.[11] A study of Italian

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(8) G.G. Fein, *et al.*, "Prenatal Exposure to Polychlorinated Biphenyls: Effects on Birth Size and Gestational Age," *Journal of Pediatrics*, Vol. 105, 1984, p. 315-320.

(9) Environmental Protection Agency, *Ambient Water Quality Criteria for Polychlorinated Biphenyls*, U.S. Environmental Protection Agency, EPA 440/5-80-068, 1980.

(10) Environment Canada (1988).

(11) D.P. Brown and M. Jones, "Mortality and Industrial Hygiene Study of Workers Exposed to Polychlorinated Biphenyls," *Archives of Environmental Contamination and Toxicology*, Vol. 36, 1981, p. 120-129.

electrical workers suggested an increase in the rates of digestive tract cancers.[12] The fact that the two groups of workers had different types of cancer casts doubt on PCBs as the causative agent, however. The statistical significance of these studies has also been a point of controversy;[13] it is claimed that the slightly increased incidence of cancer could have been due to the presence of other chemicals in the workplace or to lifestyle characteristics (alcohol consumption, low-fibre diet, etc.).

PCBs are fat-soluble compounds that tend to bioaccumulate along the food chain. Canadian aboriginal people, particularly those who eat substantial quantities of fish and game, have been found to possess relatively high concentrations of PCBs in their body fat. For example, the breast milk of Inuit women in Quebec contains the world's highest concentration of PCBs.[14] Even so, Health Canada[15] and Indian and Northern Affairs Canada[16] advise aboriginal women to breast-feed their babies on the grounds that the benefits far exceed any risk. In addition, it is noteworthy that aboriginal women have the lowest incidence of breast cancer in Canada and that Canada's Indian population has a significantly lower death rate due to cancer than has the Canadian population as a whole[17] (156 versus 170 cancer deaths per 100,000 population per year[18]). This information does not prove that PCBs do not cause cancer but it does indicate that current PCB body-fat levels do not place Canadian aboriginal populations at risk for cancer.

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(12) P.A. Bertazzi, *et al.*, "Mortality Study of Male and Female Workers Exposed to PCBs," *Proceedings of the International Symposium on the Prevention of Occupational Cancer*, Helsinki, 1981, p. 242-248.

(13) Environment Canada (1988).

(14) E. Dewailly, *et al.*, *Bulletin of Environmental Contamination and Toxicology*, Vol. 43, 1989, p. 641-646.

(15) Health Canada, "PCBs and Human Health," *Issues*, Health Protection Branch, Ottawa, 1989, 4 p.

(16) Indian and Northern Affairs Canada, *Contaminants in Northern Ecosystems and Native Diets: Summary of an Evaluation Meeting Held in Ottawa*, Ottawa, 1989, p. 7.

(17) E. Bobet and S. Darkick, "Neoplasms (Cancers)," *Coverage and Accuracy of Indian Health Data from Medical Services Branch*, Health Canada, 1994, p. 8.

(18) Data have undergone age-sex standardization and are thus corrected for differences in age distribution, life expectancy and gender-related cancers.

The EPA decision to classify PCBs as potential carcinogens was based on animal studies. Some rats fed high concentrations of PCBs over a long period were observed to have developed liver nodules and hepatomas. One might assume that these studies would have definitively established PCBs as human carcinogens; this is not so, however, as the testing procedures did not simulate real-life conditions.

Assuming that humans have the same cancer response to PCBs as do rats, then a daily PCBs dose of 7.7 mg per kg body weight per day should induce liver cancer.[19] In the United States the average individual has a PCBs intake of 0.000014 mg per kg body weight per day.[20] Accordingly, the amount of PCBs one would have to consume daily to develop liver cancer is 550,000 times greater than the level normally available in the environment. Further, one would have to ingest this large dose of PCBs every day for an extended period of time. For example, the experiment that indicated a higher-than-expected incidence of liver cancer in rats was conducted for 638 days.[21] It is unlikely that anyone would be exposed to such high PCB doses over such a long period.

Such cancer data serve little real-world purpose and call for an explanation of why they were generated. International standards for cancer research and carcinogen classification have been established by the International Agency for Research (IARC). In cancer testing, it is often very difficult and time-consuming to establish cause and effect when the suspected carcinogen is present at normal environmental or occupational concentrations. The entire testing procedure can usually be speeded up by subjecting animals "to a maximum tolerated dose of a substance over their lifetimes."[22] In cancer studies such "heroic dosing" can save both time and money; however, it can also lead to data of questionable utility when, as in the case of PCBs, massive doses of a relatively non-toxic substance are administered.

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(19) C.C. Travis and S.T. Hester, "Global Chemical Pollution," *Environmental Science and Technology*, Vol. 25, 1991, p. 814-819.

(20) M.J. Gartrell, *et al.*, "Pesticides, Selected Elements, and Other Chemicals in Adult Total Diet Samples," *Journal of the Association of Official Analytical Chemists*, Vol. 69, 1986, p. 146-159.

(21) R.D. Kimbrough, *et al.*, "Induction of Liver Tumors in Sherman Strain Female Rats by Polychlorinated Biphenyl (Aroclor 1260)," *Journal of the National Cancer Institute*, Vol. 55, 1975, p. 1453-1459.

(22) R.J. Moolenaar, "Overhauling Carcinogen Classification," *Issues in Science and Technology*, Vol. 8, 1992, p. 70-75.

This abberation in the IARC cancer-testing methodology is a recognized problem and efforts are being made to change either the methodology or the IARC carcinogen classification system.[23] Reform in this latter area is hampered by the fact that the world needs a standardized cancer-testing regime and the IARC system has been in effect for some time. Theoretically, this system should not cause problems; knowledgeable professionals usually ignore non-real-world data. For example, in the United States neither the American Conference of Governmental Industrial Hygienists nor the Occupational Safety and Health Administration, both of which are concerned with the establishment of safe chemical exposure limits in the workplace, lists PCBs as a suspected human carcinogen.[24][25]

Problems do arise in the environmental field, however, for the EPA strictly adheres to the IARC system.[26] Once the EPA lists a chemical as a possible carcinogen, environmental groups and the media are at liberty to describe that chemical as cancer-causing or linked-to-cancer. On a positive note, the EPA recently announced that it has begun the process of revising its guidelines for carcinogenic risk assessment. The new system will take into consideration "realistic exposure scenarios and mechanisms [of action] when calculating a chemicals's hazard to humans."[27]

WHY BAN AND DESTROY ALL PCBs?

PCBs exhibit two characteristics that justify the Canadian decision to ban, collect and systematically destroy all such chemicals. First, PCBs are such extremely stable compounds that they are nearly indestructible in the natural environment. Like many xenobiotics (man-made chemicals with no precedence in nature), PCBs have very few natural enemies. That is to say,

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(23) *Ibid.*

(24) *Ibid.*

(25) M.A. Ottoboni (1984)

(26) R.J. Moolenaar (1992)

(27) D.J. Hanson, "EPA to Revise Cancer Guidelines To Incorporate More Than Tumors," *Chemical and Engineering News*, 26 September 1994, p. 21-22.

microorganisms that normally degrade and recycle wastes have been slow to evolve and develop enzyme systems capable of the dedicated total degradation of PCBs. Many xenobiotics are reactive, and susceptible to light, chemical or thermal decomposition. In contrast, the chlorination of biphenyl rings produces a chemical structure of exceptional stability, which is highly resistant to physio-chemical reactions. As a result, PCBs manufactured in the 1930s are with us today and will persist for centuries unless incinerated at high temperatures or destroyed by one of the new destruction technologies under development. This environmental persistence has resulted in the dispersion of PCBs to all reaches of the globe.

The second problematic characteristic is that PCBs are highly fat soluble and conversely highly water insoluble. Thus, when they are ingested, primarily from fish, they are not readily eliminated from the body in the urine. Rather, they dissolve in digestive fats and become absorbed and accumulated in the fat reserves of the body. The concentration of PCBs accumulated in fat increases with progression up the food chain. While ill-health cannot be correlated with the current PCB body-fat loads of Canadians, it can be the argued that continued use and unrestricted disposal of PCBs might lead to ever higher body loads with unknown and possibly deleterious consequences.

THE NATIONAL INVENTORY OF PCBs

The federal government decision to ban, collect and destroy all PCBs necessitated the compilation of a national PCB inventory. Between 1929 and the late 1970s, 40,000 tonnes of PCBs were imported into Canada. No PCBs were manufactured in Canada. An inventory published by Environment Canada in 1985 accounted for 24,300 tonnes of PCBs, either in storage or in use in electrical equipment.(28) It is assumed that the PCBs not accounted for have either entered the environment,(29) or are contained in a few, as yet unaccounted, for pieces of equipment. In 1988 the Canadian Council of Resource and Environment Ministers

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(28) Environment Canada, *National Inventory of Concentrated PCB (Askarel) Fluids (1985 Summary Update)*, EPS 5/HA/4, Ottawa, 1986, 15 p.

(29) Environment Canada (1988).

published a national inventory of PCB waste storage sites.[30] This inventory identifies the owner or operator by company name and address and volumes of waste. The waste is characterized as "high concentration," "low concentration" or "concentration unknown."

The PCB inventory is not static. As PCB-containing equipment is retired, the PCB inventory at a site will increase. PCBs may be moved in efforts to consolidate stored materials, and PCB inventories will diminish as PCBs are destroyed. PCB storage regulations require the maintenance of accurate records so that at any one time the location and amount of Canada's PCBs are known; however, the original or "master" PCB inventory is updated only periodically.

Since 1988, virtually all waste PCBs in the province of Alberta have been incinerated. In Labrador, a federally operated mobile incinerator has destroyed 3,500 tonnes of federally owned PCB-contaminated wastes collected from abandoned military sites. In addition, PCB-contaminated oils and tars are being incinerated as part of the clean-up of the Sydney tar ponds in Nova Scotia.

JURISDICTION

In a judgment handed down on 23 January 1992 in *Friends of the Oldman River Society* v. *Canada*, the Supreme Court of Canada stated that the environment is a shared jurisdiction. This is very much the case with the management of waste PCBs. The federal government, as stated in *Canada's Green Plan*, is obligated to destroy all federally owned PCBs by 1996. The destruction of privately owned or provincially owned PCBs is the responsibility of the provinces. To date, Alberta is the only province to have established a PCB incinerator and to have essentially destroyed all stocks of waste PCBs. Private Albertan companies are responsible for paying the cost of PCB transportation to, and for PCB incineration at, the Alberta Special Waste Treatment Centre in Swan Hills.

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(30) Canadian Council of Resource and Environment Ministers, *National Inventory of PCB Waste Storage Sites*, 1988.

As described below, the federal government has enacted a number of regulations to ensure the safe management of PCBs. These regulations serve as a minimum standard across Canada. The provinces may enact their own PCB regulations; however, these regulations should be equivalent to or more stringent than the federal regulations. For example, the federal government has set a minimum "destruction and efficiency" standard of 99.9999% for PCB incinerators. This does not mean that the provinces must destroy their PCBs by incineration, but it does obligate them to set 99.9999% as the minimum destruction and efficiency standard for whatever destruction technology they choose.

FEDERAL HAZARDOUS WASTE MANAGEMENT REGULATIONS

The *Canadian Environmental Protection Act* (CEPA) consolidates previously existing legislation and new, and potentially far-reaching, provisions on toxic substance management.[31] In addition, the *Transportation of Dangerous Goods Act* regulates the transport of hazardous wastes, including PCBs. This Act outlines the proper handling, packaging, and labelling of transported goods, and safety during transport. Generally, the federal regulations and guidelines for collection, transportation and storage are the same for all hazardous wastes, including PCBs. Additional regulations for PCBs have been enacted for, unlike hazardous wastes that may be degraded by a variety of processes or recycled, PCBs may have to undergo long-term storage before they are destroyed. These additional regulations are the: Federal Mobile PCB Treatment and Destruction Regulations (3 January 1990), PCB Waste Export Regulations (15 August 1990), Storage of PCB Wastes Interim Order (13 October 1990), and the Chlorobiphenyls Regulations (13 March 1991).

The Federal Mobile PCB Treatment and Destruction Regulations set PCB clean-up and emission standards for mobile incinerator systems. For example, the PCB destruction and removal efficiency for a mobile unit is set at no less than 99.9999%. Very stringent environmental emission standards for dioxins, furans, hydrogen chloride, and particulate matter

(31) M. Walters, "Ecological Unity and Political Fragmentation: the Implications of the Brundtland Report for the Canadian Constitutional Order," *Alberta Law Review*, Vol. 29, 1991, p. 420-449.

are set. The efficiency of a mobile unit must be tested prior to and during operation and the regulations outline the tests to be performed. Test results must be submitted to the Minister of Environment in writing within 60 days of test completion.

The PCB Waste Export Regulations prohibit the export of any PCB wastes. Export to the United States EPA is exempt, as is the export of equipment in good working order that contains less than 500 g of PCB. The purpose of these regulations is to eliminate the risk of a spill of Canadian PCBs in a foreign country or on the seas during transport and to improve international relations and prestige through the government's commitment to manage all Canadian PCBs in Canada.

The Storage of PCB Wastes Interim Order encompasses and extends previous hazardous waste storage regulations and guidelines, giving special attention to:

- strict control of access to a storage site to prevent the entry of unauthorized persons;
- fire control (drums piled only two high, PCBs separated from other materials by a fire-resistant barrier or sufficient space to prevent combustion, exhaust system equipped to limit/contain release of smoke in event of a fire, rust prevention on drums, fire control and emergency procedure plans developed in consultation with fire department, alarms, equipment); and,
- improved maintenance and inspection, particularly in the areas of labelling requirements, maintenance of records and reporting to the Minister.

The Chlorobiphenyls Regulations, which revoke and replace Chlorobiphenyl Regulations Nos. 1, 2 and 3, prohibit the manufacture, processing, use, offer for sale or import of chlorobiphenyls. They set the maximum concentrations or quantities that may be released into the environment in the course of a commercial, manufacturing or processing activity and limit to 50 ppm the concentration of PCB in any product or piece of equipment manufactured or imported into Canada.

PCB DESTRUCTION TECHNOLOGIES

A. Incineration

To date, incineration is the only proven, relatively low-cost means of total destruction of PCBs. PCBs are very stable molecules with a very high temperature of

combustion; they are generally incinerated at temperatures of 1200°C or higher. Thus, incinerators for PCBs require special high temperature design and accordingly are more expensive to build and operate than the conventional incinerators used for most organic hazardous wastes. Incinerators designed for PCB destruction can, however, be used subsequently for the incineration of other wastes at reduced temperature and expense. Maintenance of a high flue gas temperature before, during and after the PCB incineration guards against the generation of dioxins and furans, while scrubbers ensure that carbon dioxide and water vapour are essentially the only stack emissions released to the atmosphere. PCB incinerators operate at between "six and eight 9's" (99.9999 -99.999999%) of destruction and removal efficiency.[32]

There are three types of PCB incinerator: liquid injection, rotary kiln, and high-efficiency boilers. In Canada, the rotary kiln incinerator appears to be the technology of choice as it can handle both PCB-contaminated solid wastes and liquid PCBs. The Swan Hills incinerator and the Labrador mobile unit are both rotary kilns.

In spite of the exceptional efficiency of today's toxic waste incinerators, a German company, BASF, has improved upon the technology.[33] BASF developed a catalyst (titanium, vanadium oxide and tungsten oxide) that destroys chlorinated organic compounds, converting them to carbon dioxide, water vapour and hydrogen chloride. The catalyst, by not allowing the formation of elemental chlorine, ensures that new chlorinated compounds are not created in the flue gas, thus reducing the need for scrubbers. In addition, the catalyst keeps on working for up to three hours. This has two advantages: it saves on after-burn fuel costs and it ensures a continued clean burn in the event of a plant emergency.

Virtually all environmental groups who campaign against toxic chemicals are unanimously opposed to incineration as a toxic waste management strategy. These groups promote the belief that incineration simply takes a concentrated toxic waste and disperses toxic fumes through the air over a wider area. Although this allegation is no longer valid, there are

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(32) C.C. Travis and S.C. Cook, *Hazardous Waste Incineration and Human Health*, CRC Press, Boca Raton, FL, 1989, 154 p.

(33) A. Coghlan, "Dioxin Destroyer Makes Incinerators Better Neighbours," *New Scientist*, 16 January 1993, p. 19.

some historical data to support it. Up to approximately 30 years ago it was common practice in North American cities to burn garbage in municipal solid waste incinerators that were not equipped with any sort of pollution-control device. Today, soil analyses in the vicinity of these old incinerators still reveal the presence of dioxins and furans. It could therefore be argued that incineration takes PCBs and thermochemically transforms a portion of them to the more toxic and truly carcinogenic compound dioxin.[34]

Nevertheless, a simple mathematical check shows that the dioxin risk posed by a PCB incinerator is indeed minimal. A high-temperature burn of chlorinated organic compounds can generate a dioxin flue gas concentration of 5 to 50 ppm.[35] In a worst-case PCB-incineration scenario, the dioxin concentration would be 50 ppm and the incinerator would be operating at the minimum destruction and efficiency standard permitted (99.9999%). Under these conditions, out of every million organic molecules generated by the burn only one molecule would escape to the atmosphere; the chance of that molecule being dioxin is one in 20,000.

Environmentalists argue that any exposure to dioxin, no matter how small, represents an unacceptable health risk. This may be true; however, every day virtually everyone on this planet is subjected to dioxins from uncontrolled emissions of cigarette smoke, wood smoke, and furnace gases. According to a Japanese study:

> The concentration of PCDDs [dioxins] in cigarette smoke was similar to that found in the flue gas of a municipal waste incinerator. However, the presence of PCDDs in cigarette smoke is more significant than that in the flue gas because cigarette smoke is inhaled directly into the lungs without diffusion and/or dilution.[36]

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(34) "Dioxins and Furans - A Backgrounder," *Canadian Environmental Control Newsletter*, Vol. 428, 1991, p. 3537-3539.

(35) *Ibid.*

(36) H. Muto and Y. Takizawa, "Dioxins in Cigarette Smoke," *Archives of Environmental Health*, Vol. 44, 1989, p. 171-174.

B. Chemical/Thermo-Chemical/Mechano-Chemical Technologies

The decontamination of mineral oils containing up to a few thousand ppm of PCBs can be achieved by a chemical-sodium process. Here, the sodium reagent strips chlorine atoms from the PCB molecule and produces polyphenylene and sodium chloride. The mineral oil in which the PCBs were dispersed is unchanged and can be reused. Unfortunately this process has a number of disadvantages: it is very expensive, it produces a large salt waste stream, it cannot be used in cases where the oil also contains significant amounts of contaminating water, and it is appropriate only for the clean-up of oils containing low concentrations of PCBs. In 1991, the German company Degussa announced a new sodium-based process that it claims will detoxify oils at low cost;(37) however, further details have not been made available.

A Canadian company, Eco Logic of Rockwood, Ontario, has developed a thermo-chemical process whereby the PCB wastes are placed in a closed vessel and hydrogen is injected to replace air as the headspace gas. When oxygen is eliminated in this manner the PCBs cannot be oxidized to dioxins. The reaction is started by heating the reactor contents to temperatures above 850°C. The PCBs undergo a chemical reduction reaction whereby each of the chlorine atoms is replaced by a hydrogen atom. The hydrogenated biphenyl rings then cleave to produce two molecules of benzene. The released chlorine atoms react with more hydrogen to form hydrochloric acid. Finally, the hydrochloric acid is treated with sodium bicarbonate to produce sodium chloride and methane gas.(38)

This Canadian process has a number of advantages. Most important, it emits no flue gases and can therefore be marketed as a "closed system." The apparatus is not large and can be used as a mobile facility. In addition, the process produces two commercially valuable commodities, benzene and methane. In controlled laboratory conditions, destruction and efficiency levels of 99.9999% have been achieved. Environment Canada and the United States EPA are jointly funding a pilot study to determine if the same level of destruction and efficiency can be duplicated under "use" conditions for a variety of PCB wastes. The process is not without its disadvantages, however. It produces a salt waste stream, and treatment costs can run up to $1,000 per tonne.

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(37) B. Fox, "How Metal Makes Toxic Waste Safe to Burn," *New Scientist*, Vol. 22, 1991, p. 28.

(38) D. Suzuki, "Stunning New Method Zaps Toxic Chemicals Efficiently," *Toronto Star*, 30 January 1993, p. D6.

It should be noted that two substances in the Eco Logic process, hydrogen and benzene, are potentially hazardous in an emergency situation. Hydrogen is an extremely explosive substance, while benzene is both very toxic and a recognized carcinogen. Chronic exposure to benzene causes depression of bone marrow activity, aplasia (tissue or organ failure to develop), and leukaemia. Acute exposure may result in irritation of mucous membranes, restlessness, convulsions, excitement, depression and death from respiratory failure.(39)

Australian researchers have patented a mechano-chemical process for the degradation of PCBs and other chemical wastes. This is a closed system where PCB waste and a reactant such as calcium oxide are placed in a ball mill containing steel balls. The colliding balls are said to activate chemical reactions resulting in "virtual" breakdown of the waste to environmentally harmless products such as carbon, calcium hydroxide and calcium chloride at a destruction and efficiency level of 99.996%. Unlike other PCB destruction processes, this system requires no heat input. In addition, it can be used as a mobile facility.(40) Critics of the system point out that the technique is still in an early development stage and there are as yet insufficient data to judge the validity of process claims. Scepticism tends to be high as another process using calcium oxide was shown to volatilize PCBs rather than degrade them.(41)

C. Biological Degradation

The Biological Sciences Laboratory of General Electric Co., Schenectady, N.Y. is conducting research on the biological degradation of PCBs. Until the early 1980s it was firmly believed that PCBs were biologically indestructible; however, analysis of a 30-year-old PCB dump in the oxygen-depleted (anaerobic) sediments of the Hudson River show PCBs to have been largely dechlorinated by the action of anaerobic bacteria. Transfer of these dechlorinated biphenyl rings to an aerobic atmosphere resulted in further degradation by oxidative bacteria.(42)

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(39) M. Windholz, *et al.*, (eds.), *The Merck Index*, Merck & Co., Inc., New Jersey, 9th edition, 1978, p. 1066.

(40) S.A. Rowlands, *et al.*, "Destruction of Toxic Materials," *Nature*, Vol. 367, 1994, p. 223.

(41) S. Borman, "New Idea Developed to Destroy Toxic Chemicals," *Chemical and Engineering News*, 11 October 1993, p. 5.

(42) J.F. Quensen, *et al.*, "Reductive Dechlorination of Polychlorinated Biphenyls by Anaerobic Microorganisms from Sediments," *Science*, Vol. 242, 1988, p. 752-754.

It is believed that, during the 30-year incubation of PCBs in the presence of anaerobic bacteria, sufficient evolution and genetic exchange occurred to produce new strains of PCB-dechlorinating bacteria. General Electric is carrying out research and development work to optimize a sequential anaerobic-aerobic process. Genetic engineering work is also underway to place all the necessary genes in one microorganism so the process can be accomplished in one step.[43] This is a long-term research project, and its successful commercial application may be many years, if not decades, in the future.

THE CURRENT SITUATION

Following the PCB fire in St.-Basile-le-Grand in August 1988, federal and provincial regulations and monitoring of hazardous waste storage and destruction facilities have become much more stringent and there have been no reports of major accidents or releases of PCBs from storage sites or hazardous waste transfer stations. There have, however, been, a few reports of minor leaks and spills and PCBs were spilt on the road in a highway accident.

Hazardous waste and PCB storage sites now appear to be well operated and safe. This is not to say that the storage of hazardous wastes should be considered as a waste disposal solution. No matter how safe a storage facility, there is always the possibility of a chemical disaster due to arson or a catastrophic act of nature. Further, the economic burden means that indefinite storage of toxic wastes such as PCBs cannot be seriously considered. Indeed, the cost of "in-perpetuity" storage might induce owners not to declare PCB inventories and to dump the chemicals illegally into landfills, sewers, or waterways.

DISCUSSION

The Canadian effort to manage waste PCBs effectively has been stalled by misconceptions held by the public. The federal and provincial governments must carry some

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(43) F.J. Mondello, "Cloning and Expression in *Escherichia coli* of *Pseudomonas* Strain LB400 Genes Encoding Polychlorinated Biphenyl Degradation," *Journal of Bacteriology*, Vol. 171, 1989, p. 1725-1732.

of the responsibility for this. Though this paralysis is costing Canadian tax payers and businesses enormous sums of money in maintenance, supervision and inspection of PCB storage sites, governments have made very little effort either to disseminate PCB facts or to counter PCB myths.

The Green Plan calls for the destruction of all federally owned PCBs by 1996 and the government has initiated a consultative procedure to ensure public participation in the decision-making process for the siting of mobile incinerators. It is questionable, however, whether members of a community are capable of reaching an informed decision on this subject if they have only their fears and scant factual knowledge of PCBs or PCB incineration to guide them. Indeed, even the well informed individuals in a community will oppose local PCB incineration on the grounds that resulting neighbourhood fears and sensational media reports would lower property values.

An additional problem confronting Canada's PCB destruction program stems from the actions of some environmental groups. Although these groups support the elimination of PCBs, they are so opposed to incineration that some attempt to block even equipment testing. No matter what technology is used to destroy PCBs, it is essential that all equipment undergo rigorous quality-control testing to supply the critical data needed for comparing competing technologies and to ensure that the chosen technology will meet federal emission standards. In the United States, an environmental group obtained a court injunction to block a 1993 EPA test burn at the state-of-the-art Von Roll toxic waste incinerator in East Liverpool, Ohio.[44] In Canada, opposition to, and criticism of, test burns at both the Sydney tar ponds and the Labrador mobile PCB incinerator received widespread media coverage.

Given the opposition to quality-control tests for incinerators, it should not be expected that alternative technologies will receive carte blanche acceptance. Indeed, scepticism towards and resistance to these technologies could be expected since, as yet, none of them has achieved the eight 9's level of efficiency and destruction demonstrated by the best PCB incinerators.

Misinformation and a failure to dispel environmental misconceptions have greatly impaired the effectiveness of Canada's PCB destruction program. As a result, PCBs are being relegated to long-term storage, the solution that poses the greatest threat to the Canadian environment.

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(44) "Greenpeace Calls a Judge," *Wall Street Journal*, 19 January 1993, p. A14.

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